18th March 2002
XXVIII Rencontres de Moriond

On behalf of ZEUS and H1
University of Bristol

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Jet Physics and Event Shape Studies at HERA
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**Boson-Gluon Fusion**

**QCD-Combination**

**Quark-Parton Model**

Up to jet production occurs via:

\[
\frac{b_d I_z}{\not{z}O} = x
\]

\[
\not{z}(p_{\perp} - \not{\ell} - \not{b} - \not{c} - \not{O}) = 300 \text{ GeV} \approx s^{1/2}
\]

**Kinematics:**

DEEP INELASTIC SCATTERING AT HERA
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\[ 0 = b + d x^2 \]

\[ \text{quark out} \]

\[ (n d) d \]

\[ b \]

\[ \text{quark out} \]

\[ d \]

\[ \text{quark out} \]

2 possible hard energy scales \[ \implies \frac{E}{}\frac{E}{T} \]

Jet studies in the Breit frame:

- Extraction of \[ q_s^8 \]
- Sensitivity to parton densities (PDFs)
- Test of pQCD calculations
- Inclusive jet / dijet cross sections

**Jet Production in DIS**
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\[ \phi = \phi_{\text{jet}} - \phi_{\text{W}} \]

**Inclusive observation in jets of**

\[ A + C \cos 2\phi \]

**Jet cuts ONLY in Brit frame:**

- $E_T > 1.8 \text{ GeV}$
- $p_T > 8 \text{ GeV}$

**Kt-cluster algorithm used**

- Assure good reconstruction
- $E_T > 0.7 \cos \theta > 0.2$
- $\theta < 125 \text{ GeV}$

**1996-97 Data, Kinematic Range**

- Smaller theoretical uncertainties compared to dijet calculations
- No infrared sensitivity problems related to the jet selection cuts as in dijet analyses

**Advantages of inclusive measurements:**

- IN DIS IN THE BRIT FRIEME

**Inclusive Cross Sections**
The extraction method of $\alpha_s$ from inclusive cross sections is very sensitive to the value of $\alpha_s$ and falls over 5 orders of magnitude over all $Q^2$ range (within 10–15%) and $0 < \theta < \pi$. Reasonable NLO description of the data.
NLO describes data reasonably well.

Good description of the jet azimuthal energy flow.

\[ \Delta \phi = \phi_{HFS-jet} - \phi_{\text{jet}} \]

\[ 1 \times 10^{-1} \leq \eta_{\text{jet}} \leq 0.5 \]

\[ 2.5 \leq \eta_{\text{jet}} \leq 1.5 \]

\[ \frac{1}{2} \leq E_T^{\text{jet}} \leq 28 \text{ GeV} \]

\[ \frac{1}{2} \leq E_T^{\text{jet}} \leq 75 \text{ GeV} \]

\[ 0.1 \leq y \leq 0.5 \]

\[ 0.5 \leq y \leq 0.9 \]

\[ Q^2 \leq 1 \text{ GeV}^2 \]

\[ \text{incl. kT algor.} \]

In photoproduction

Inclusive High-$E_T$ jet cross sections
from NLO

\( \Delta \alpha_s \) Good description

\( R^2 + 1 \) with \( Q^2 \)

\( Q^2 \) (GeV)

\( r^2 \) from QCD fit up to \( Q^2 \)

extracted

\( \alpha_s \) suited for \( \alpha_s \) extraction

as \( \exp \) on uncertainties largely cancel in the ratio

not very sensitive to PDFs

\( \frac{\mu d \sigma}{1 + 2 \alpha_s} = (\frac{\alpha_s}{2})^{1 + 2 \alpha_s} \)

\( \tau \) from DiJet Rates at High \( \tau \)

\( E_T^{\tau} > 5 \) GeV, \( E_T^{\tau} < 8 \) GeV

\( E_T^{\tau} > 8 \) GeV, \( E_T^{\tau} < 20000 \) GeV

- \( l^+ l^- > 2 \)

- \( -l^+ l^- > 2 \)
describe data
but NLO unable to
smaller scale unc.
but NLO describes data
large scale unc.

\[ \mu_{\text{scale}} \]

\[ \mu_{\text{2}} \]

Dijet rate \( R_2 \) (\( \text{Et,jet}_1 > 7 \text{ GeV} \)\)

H1 data (preliminary)

NLO (DISENT)

\[ \mu_{\text{2}} \]

\[ \mu_{\text{2}} \]

\[ \mu_{\text{2}} \]

\[ \mu_{\text{2}} \]

Motivations:

Dijet Rates at Medium \( Q^2 \)
Motivations:

Jet Production in DIS at Small Jet Separation

1995-97 Data, Kinematic Range

1.3 events classified as dijets for $y_D < 0.001$

$Q^2 > 150 \text{ GeV}^2$

1.5 $> y > 0.17$

$\sqrt{s} > 35000 \text{ GeV}$

RAPGAP performs very well over all $y_D$ range

For $y_D < 0.001$, NLO describes data well:

\[
\frac{1}{\sigma_{\text{theory}}} \frac{\sigma_{\text{data}}}{\sigma_{\text{NLO}} \otimes (1 + \delta_{\text{had}})} \approx \frac{\sigma_{\text{data}}}{\sigma_{\text{NLO}} \otimes (1 + \delta_{\text{had}})}
\]

\[
\frac{M}{\ln \frac{M}{\min \sqrt{s}}} \approx y_D
\]
BUT need for more stats ...

largely cancel in the ratio

$Q^2$ range, and the $f_H$ and gluon PDF dependencies

NLO describes the data reasonably well over all

$-1 < \frac{\mu_r}{\mu_F} < 2.5$

$E_T^{jet} < 5$ GeV

$N$-jet cluster algorithm applied in Breit frame

$1995-97$ data, Kinematic range

Motivations:

$10 \text{ jet-jet production in DIS}$

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\[
\left( \frac{N}{0.189 - 0.115 \pm 0.0016 \text{stat} \pm 0.004 \text{sys}} \right)_{\text{CAB}} = \left( 1.1 \right)^{n} \left( Z_{\text{N}} \right)_{\text{C}} ^{n}
\]

**ZEUS**

Jet measurement is rather sensitive to N, not suited for N extraction.

- NLO QCD describes the data
- \( E_{T} > 15 \text{ GeV} \) + \( n_{\text{jet}} > 1 \)
- \( \Omega_{\text{jet}} > 1.25 \text{ GeV}^{2} \)

Cluster algorithm in the LSF frame

Jet substructure with subject infrared-safe to all orders theoretically interesting

NCS FROM SUBJET MULTIPOLARITIES
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\[ (\phi, \eta) = \left( \frac{d^2 \sigma}{d\phi d\eta} \right) \left( 0.1179 \pm 0.0094 \text{ (stat)} + 0.0054 \text{ (sys)} \right) \]

**ZEUS**

*Suitable for \( q^* \) extraction but measurement is rather sensitive to \( q^* \) (not shown)*

NLO describes the distributions \( f^* \) very well. The measurement is not shown.

*Jet substructure at high \( \eta^* \) relative to the jet axis and effects are less important*
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- HI also fitted the event shape distributions
  \( \rightarrow \) dim. fits to data
  - \( \alpha_s \) and non-pert. parameter \( \alpha \)
  - Power corrections depend on
    - NLO program
    - Non-perturbative effects
    - Event shapes \( \mathcal{P} \) computed with
      \( \mathcal{P} \)

**Theory:**

\[
\mathcal{P} = \frac{\left\langle \mathcal{P} \right\rangle_{\text{pole-corr.}}}{\left\langle \mathcal{P} \right\rangle_{\text{rescaled}}} = \frac{\left\langle \mathcal{P} \right\rangle_{\text{pole-corr.}}}{\left\langle \mathcal{P} \right\rangle_{\text{rescaled}}}
\]

ZEUS assumes massive hadrons

- HI uses massive hadrons

\[
\frac{\left\langle \mathcal{P} \right\rangle_{\text{pole-corr.}}}{\left\langle \mathcal{P} \right\rangle_{\text{rescaled}}} = \frac{\left\langle \mathcal{P} \right\rangle_{\text{pole-corr.}}}{\left\langle \mathcal{P} \right\rangle_{\text{rescaled}}}
\]

Jet broadening

\[
\frac{\left| d\mathcal{P} \right|}{\left| d\mathcal{P} \right|_{\text{rescaled}}} - 1 = \frac{\left| d\mathcal{P} \right|}{\left| d\mathcal{P} \right|_{\text{rescaled}}} - 1 = \frac{\left| d\mathcal{P} \right|}{\left| d\mathcal{P} \right|_{\text{rescaled}}} - 1
\]

**Event shape variables:**

- **Power Corrections and Resumptions:**

\[
\text{Event Shapes} \quad \text{variable}
\]
ZEUS and H1 data agree in general within errors, but some discrepancies still remain. General reasonable and consistent description. Spread in $\sigma_{W}$ suggests need for higher order corrections. Fits suggest $\alpha^{0} \approx 0.5 \pm 20\%$.

$\alpha^{s}(M_{Z})$ mass effects important for jet mass $0 = \mu^{+} \Leftrightarrow \mu^{-}$, $0 \neq \mu^{+} \Leftrightarrow \mu^{-}$.

**Power Corrections and Resummation**
Preliminary studies of event shape distributions are encouraging.\[\overline{\chi}^2\] data on jet mass and thrust \(t\) (wt. thrust axes) spectra and QCD resummed results can resummed QCD calculations help? \(\overline{Q}^2 = 0.1\) has performed fits also to event shapes spectra:

**Power Corrections and Resumptions (III)**

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**Jet Physics and Event Shape Studies at HERA**

E. Rodriguez

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The various $\alpha_s$ extracted values are consistent with each other and the world average. Further studies at HERA will strongly benefit from higher order theoretical calculations.

But the theoretical uncertainties are among the largest, and limit high precision QCD tests.

Conclusions